ANSI STANDARD

CODE OF STANDARD PRACTICE

FOR FABRICATION AND INSTALLATION

OF PULTRUDED FRP STRUCTURES

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PREFACE

The vision to develop a load resistance factor design standard was started in mid-1990 by the Pultrusion Industry Council of the Society of the Plastics Industry – Composites Institute. In the coming years, the American Society of Civil Engineers (ASCE) was commissioned to help the PIC explore test data and literature performed on FRP pultruded composites, specifically structural shapes to determine if enough data exists to develop the design standard. It was concluded that sufficient data existed and a proposed outline established that defined the design standard.

In August 2007, the American Composites Manufacturers Association (ACMA) commissioned the ASCE to produce the Load Resistance Factor Design (LRFD) Standard for Pultruded Fiber Reinforced Polymer (FRP) Composite Structures. This 3-year project was made possible by the involvement, commitment and support of ACMA member companies, primarily the Pultrusion Industry Council. ASCE assembled a team of authors with experience and knowledge in FRP composites testing, design and standards writing to prepare the chapters and commentary for the standard. Dr. Mehdi Zarghamee, Simpson Gumpertz & Heger Inc. was selected by ASCE to serve as the Project Coordinator and during the course of this project helped to ensure accuracy, consistency, and balance in the development of this standard.

The Pultrusion Industry Council then initiated the development of this Code of Standard Practice to serve as a companion document to the published ASCE standard. This publication is intended to provide recommendations for construction contract documents, as well as procedures and practices for the fabrication and installation of pultruded FRP structures that is followed by the pultrusion industry manufacturers.

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1.0 GENERAL SCOPE

1.1 Scope

This *Code of Standard Practice* provides recommendations for construction contract documents, fabrication and installation of pultruded FRP structures. In the absence of other instructions in the particular contract documents that take precedence over the practices provided in this *Code of Standard Practice* these practices are recommended by reference for the fabrication and installation of pultruded FRP structures.

1.2 Definitions

The following are definitions of terms specific to this *Code of Standard Practice.*

ACMA – American Composites Manufacturers Association

Architect/Engineer – The Owner's designated representative with full responsibility for the design and construction integrity of the structure.

Architecturally Exposed FRP – Members, whether or not specifically designated by the contract documents as "Architecturally Exposed FRP" of non-standard characteristics that require special care in manufacture, fabrication and/or assembly.

ASCE – American Society of Civil Engineers

ASTM – ASTM International (formerly American Society for Testing and Materials)

Code – The Code of Standard Practice for Fabrication and Installation of Pultruded FRP Structures.

Contract Documents – These documents include the contract agreement, plans and specifications that define the project scope and parties in bidding, selling, purchasing, manufacturing, fabricating, supplying and installation of FRP structural components and structures.

Engineer-of-Record (also noted as Engineer) – The licensed professional contracted by the Owner that is responsible for sealing the design documents.

FRP – Fiber Reinforced Polymer (understood to be pultruded in this document)

FRP Drawings – Manufacturing shop and field assembly/installation drawings prepared by the Manufacturer, Fabricator and Installer for the performance of the work.

Fabricator – The party responsible for furnishing fabricated (assembled) FRP structural components.

Fiber Reinforcement - The reinforcing materials including the glass, carbon and/or other filaments and their surface, sizing binder incorporated into the FRP composite during the manufacturing process. Common types of reinforcements are glass fibers and carbon fibers and are manufactured in the form of rovings, strand or tow, continuous mat, stitched mat or woven mat forms. Orientation and volume of the fiber types and forms govern the structural properties of the FRP composite**.**

Installer – The Owner's designated party responsible for assembling and erecting the FRP structure according to the engineer's plans and specifications.

Manufacturer (Composite Manufacturer or Pultruder) – The party responsible for producing the pultruded FRP structural components.

Material Certification Reports – Test reports, furnished by the Manufacturer, demonstrate that the pultruded FRP structures have been determined by the Manufacturer to be in compliance to the applicable material specifications.

Owner – The party who owns the proposed FRP structure and its designated representatives, including, among others, the architect, engineer, installer, public authority, building official or others not specifically defined in this code.

Plans and Specifications – Drawings and documents furnished by the Owner (or Owner's representative) that depict the pultruded FRP structure and system and the design criteria required.

Polymeric Resins – The FRP resin system includes the base resin, additives, fillers, catalysts, UV protection agents, fire retardants, pigments, release agents and other compounds added to this matrix in the manufacturing process. Commonly used resin systems include polyesters, vinyl esters, phenolic, polyurethane and epoxies that are compatible with the reinforcement fiber to develop desired mechanical and structural properties.

Pultruded FRP Structures – Structural FRP composites, manufactured by the pultrusion process. Each component has consistent and distinct properties and characteristics developed within the pultrusion process where the section and material properties and performance of the composites are quantified by ASTM or other authoritative test methods and protocols as applicable.

Pultrusion – A continuous process for manufacturing composites that have a constant cross-sectional shape. The process consists of pulling a fiber-reinforcing material through a resin impregnation bath and through a shaping die, where the resin is subsequently cured.

Release for Construction – The approval and/or release by the Owner permitting the Manufacturer and Suppliers to commence work under the contract, including the ordering of materials and the preparation of manufacturing and shop drawings.

Supplier – The party responsible for providing ancillary components required for the assembly and installation of FRP pultruded structures. These components include fasteners, adhesives, coatings or anything else not manufactured within the pultruded FRP composite.

Standard for the Design of Pultruded FRP Structures – The publication developed by ASCE providing design guidance for pultruded FRP structures. In the absence of other instructions this publication governs the design of pultruded FRP structures.

1.3 Reference Specifications and Standards

1.3.1 ASTM International (ASTM)

ASTM D3917 - Standard Specification for Dimensional Tolerance of Thermosetting Glass-Reinforced Plastic Pultruded Shapes

ASTM D4385 - Standard Practice for Classifying Visual Defects in Thermosetting Reinforced Plastic Pultruded Products

1.3.2 Underwriters Laboratory

UL 94 (V0) - Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances testing

1.4 Responsibility for Design

1.4.1 It is the Owner's responsibility to determine the use, function and the design criteria for the structure and to depict these in the plans and specifications. When the Owner also provides the design of the FRP structure, the Manufacturer and Fabricator are not responsible for the performance, adequacy, suitability or legality of the design. The Manufacturer and Fabricator are not responsible for the construction means, methods, techniques, sequences or procedures or for the safety programs or precautions of the assembly and installation.

1.4.2 If the Owner directs the Manufacturer or the Fabricator to provide the design requirements of the FRP structure using the Owner's design criteria, plans and specifications, these design requirements must be clearly stated in the contract documents. The shift of responsibility must be accepted in writing by the individual(s) assuming this transfer of authority and responsibility. The Manufacturer and Fabricator are not responsible for the construction means, methods, techniques, sequences or procedures or for the safety programs or precautions of the assembly and installation resulting from the Owners design requirements.

1.5 Patented Devices and Intellectual Property

It is the responsibility of the Owner to obtain any necessary intellectual property or patent rights and the Manufacturer, Fabricator and Installer are to be protected by the Owner in the use of such property or patented designs, devices or components required by the contract documents. Intellectual property and patent rights owned by the Manufacturer, Fabricator or Installer is to remain with the Manufacturer, Fabricator or Installer.

2.0 PLANS AND SPECIFICATIONS

2.1 Drawings and Design Criteria

It is the expectation of the Manufacturer, Fabricator and Installer to be provided by the Owner complete site plans and specifications "released for construction." Plans should include dimensioned drawings of the FRP structure and all criteria within the design clearly depicting the work to be performed and providing size, section and location of members, column centers, offsets and deck levels. Specifications should provide scope of work, design loads and performance limits, material types including all products and ancillary components, connections, fabrication requirements, quality control requirements and shipping and handling requirements.

2.2 Owner Responsibility

To enable the Manufacturer and Fabricator to properly proceed and expedite the work, the Owner should furnish in a timely manner according to contract documents, all site plans, drawings depicting the FRP structure and specifications “released for construction” bearing the seal of a registered engineer or architect, if so required.

2.3 Discrepancies and Dimensions

In the situation where discrepancies exist between plans and specifications, the specifications shall govern. Scaled dimensions from plans are not sufficiently accurate for use in developing structural design drawings and shop drawings for fabrication and will require field dimension surveys by the Owner. Field dimension surveys are not the responsibility of the Manufacturer or Fabricator unless the Manufacturer and/or Fabricator have been specifically contracted by the Owner to hire the development of such field surveys.

2.4 FRP Structural Design Drawings

Structural design drawings for the FRP should show clearly the work that is to be performed and give all information with sufficient details and dimensions to convey the materials and components to be manufactured and fabricated. The FRP structural design drawings are to define the loads considered and used. At minimum, the structural design drawings should show all members required, including their material, size, section, exact locations and all geometry and work points necessary for layout. All connections between the FRP members should be fully developed in the FRP structural design drawings including any required stiffeners and the type and location and gage(s) of all mechanical fasteners, any adhesives required and any other component to be incorporated. The structural design drawings should bear the seal of a registered engineer or architect, if so required.

2.5 Special Conditions

Pultruded FRP structures are to be furnished with the proprietary characteristics common to the product as developed and defined by the Manufacturer. Where “architecturally exposed FRP” or other non-standard FRP composite is required, the Owner should provide and clearly define all material characteristics, surface coating treatment requirements, color match designations, connection requirements and/or any other special conditions particular to the scope of work.

3.0 SHOP AND SHOP ASSEMBLY DRAWINGS

3.1 Description of Shop Drawings

FRP shop drawings are to contain all views, sections, details and dimensions along with bills of material including piece identification marks to clearly depict the work. Drawings should be clearly legible and are recommended to be in a scale of not less than ¼ inch to the foot. For more complex details the scale should be increased to properly convey all information clearly.

3.2 Approval of Shop Drawings

3.2.1 When FRP shop drawings are developed by the Manufacturer or Fabricator, hard copy prints or electronic formatted drawings as designated by the contract documents should be submitted to the Owner for examination and approval. The Fabricator should include a maximum allowance of fourteen (14) calendar days in its schedule for the return of shop drawings, unless noted otherwise in the contract. Return of shop drawings by the Owner is to be noted with written approval or subject to corrections as noted. The Fabricator makes the corrections, furnishes corrected prints to the Owner and is released by the Owner to begin manufacture and fabrication.

3.2.2 Any changes, additions or deletions indicated by the Owner on the approval shop drawings are authorizations to release the changes, additions or deletions for construction and fabrication.

3.2.3 Approval by the Owner of the shop drawings indicates that the contract requirements are correctly interpreted and the Manufacturer and Fabricator are released by the Owner to begin manufacture and fabrication. The Owner's approval of shop drawings constitutes the Owner's acceptance of all responsibility for the design adequacy of any detail configuration of the connections developed by the Fabricator as part of its preparation of the shop drawings. Approval by the Owner does not relieve the Manufacturer or Fabricator of the responsibility for accuracy of detail fabrication dimensions on the shop drawings or for the general fit-up assembly of components to be assembled in the field.

3.3 Shop Drawings Furnished by Owner

When FRP shop drawings are developed and furnished by the Owner, such drawings must be made available in a timely manner to permit manufacture and fabrication to proceed in accordance with the time schedule. The Owner is responsible for properly preparing all views, sections, details and dimensions along with bills of material including piece identification marks to clearly depict the work. The Owner assumes all responsibility for the completeness and accuracy of the shop drawings it furnishes.

4.0 FABRICATION

4.1 Identification and Control of Material

4.1.1 Pultruded FRP structures should be manufactured to conform to the published manufacturers material properties which are tested to ASTM protocols for that particular composite. Unless special conditions and requirements are otherwise included in the contract documents, testing by the Manufacturer need only conform to the applicable ASTM material specifications. Material Certification Reports are furnished by the Manufacturer only if requested by the Owner in the contract documents or in separate written instructions prior to the time that material orders are placed with the Manufacturer.

4.1.2 Many Manufacturers and Fabricators maintain stock inventories of pultruded FRP structures for use in fabrication. Material taken from stock inventories for use in structural applications must meet the applicable ASTM material specifications.

4.1.3 Manufacturers and Fabricators must maintain records and reports consistent with their quality control plan covering the material procured from stock, but Manufacturers and

Fabricators do not need to maintain records of individual pieces of stock material against individual test reports and Material Certification Reports.

4.1.4 Pultruded FRP structures must be marked and controlled by the Manufacturer during the manufacturing, inventorying and shipping process according to its control procedures.

4.1.5 Pultruded FRP structures must be piece marked and controlled by the Fabricator during the fabrication, assembly and shipping process according to its fabrication identification and control procedures. Assembly and sub-assembly shipping marks and piece marks should be placed on the parts according to the shop drawing nomenclature and be clear and legible throughout installation.

4.2 Dimensional Tolerances and Working Lines

4.2.1 "Standard" dimensional criteria and tolerances of pultruded FRP structures are to be according to the tolerances set forth in ASTM D3917 and are applicable to standard, rods, bars and shapes unless wider or tighter tolerances are specifically designated by the Manufacturer. The measurement of "straightness" and "twist" should be determined according to ASTM D3917 and measured when weight of pultrusion minimizes the deviation by contact with flat surface.

4.2.2 Fabrication tolerances are shop controlled deviation limits from work lines (see 4.2.3) placed upon the cutting, drilling and machining of pultruded FRP structures. In order to allow for proper alignment and fit-up using bolted fasteners with hole diameters 1/16 inch (1.6 mm) greater than the diameter of bolt (see 4.4.1.1) fabrication tolerances should not exceed the following:

Cut lengths	+/- 1/8 inch (3 mm)
Squareness of cuts	+/- 1° [1]
Hole locations	+/- 1/16 inch (1.6 mm)
Hole diameters up to ½ inch (13 mm)	+/- .015 inch (0.4 mm)
Hole diameters ½ inch (13mm) to 1 inch (25.4 mm)	+/- 1/32 inch (0.8 mm)
Hole diameters greater than 1inch (25 mm)	+/- 1/16 inch (1.6 mm)
Slots (any dimensions)	+/- 1/16 inch (1.6 mm)

[1] *For certain applications such as load bearing columns and fit-up of certain connections the squareness of cuts will need to be held tighter than indicated and for these special conditions notes on shop drawings are required to designate these particular conditions.*

4.2.3 Work lines are center lines or offset lines for depicting and locating the components into the fabrication. Figure 4.1 gives the standard work lines for various pultruded FRP components.

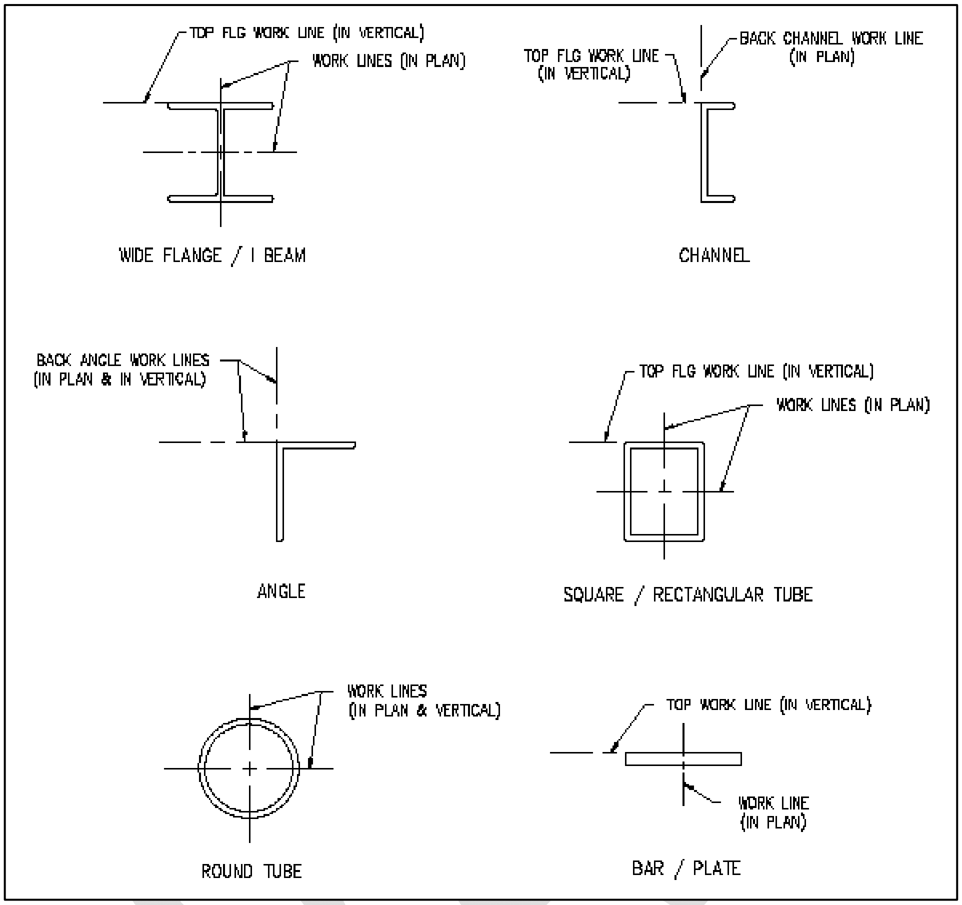

FIGURE 4.1 – WORK LINES FOR FRP COMPONENTS

4.3 Preparation of Material

4.3.1 Sawing and Other Cutting

A carbide or diamond grit edged blade is recommended for saw cutting of pultruded FRP composites. For high volume production cutting, a 30-40 or 60-80 grit diamond blade provides best results. When sawing few pieces, a disposable blade hacksaw (24-32 teeth per inch) is adequate, although a masonry blade is preferred.

In sawing and cutting operations, always provide adequate support of the work piece to keep it from shifting while making the cut. FRP components can chip and split if allowed to shift during the cutting operation. Light, even pressure should be applied as heavy pressure tends to clog the cutting blade with residue and shorten blade life. Cutting speed is also critical. Too high a speed can cause heat build-up on the blade and the work piece edges to discolor or fray. Other than conventional sawing and cutting operations under dry conditions water cooling can also be incorporated. Water cooling is generally used for very high volume or when thick cross sections are being cut. Cutting speeds increase with water cooling and dust is eliminated; however, disposal of the contaminated cutting water is a consideration.

Water jet cutting is also an option for high production operations. A manufacturer of water jet equipment should be consulted for this method.

Routers can also be used for cutting of curves and circles. Routers should be equipped with carbide (6,000-10,000 RPM) or diamond (15,000-24,000 RPM) gritted rotary bits. The same considerations as for saw cutting apply to this method.

In sawing and cutting, as well as sanding or abrading, the generation of dust is a consideration. Dust from carbon fiber is also electrically conductive and additional considerations would apply.

4.3.2 Punching and Shearing

Pultruded FRP composites can be punched with a die punch; however, the ability to punch is dependent upon thickness of the component and the application. Unlike punching metallic product, pultruded FRP will spring back. The abrasiveness of FRP must also be considered when punching or shearing is attempted. Punching and shearing should be completed with custom tooling that is equipped with a specially shaped die that allows only a small area of the cutting edge to penetrate the composite at any one time. A punch should also be equipped with a stripper system so that it can be removed without cracking the composite. Punching and shearing of pultruded FRP are sensitive to composite thicknesses and fiber reinforcement and require very precise tolerance equipment, lubricants, special punching dies, tools and hardware. The manufacturer of the composite material should be contacted if further information is needed.

4.3.3 Drilling

Carbide tipped counter-bore fluted or diamond grit core drill bits are recommended. Pressure on the drill tip and the drill speeds should be low enough to not clog the cutting tip with residue or cause heat build-up in the work piece.

4.3.4 Sanding and Abrading

Pultruded FRP composites can be sanded or abraded to remove surface finishes and surfacing veils. Very light pressure on a high speed sanding wheel with open grit (40-80) sandpaper yields the best results. Heavy pressure will tend to cause heat build-up in the FRP. Grinding is generally not recommended without the use of water coolant. A coarse grit wheel should be used for grinding.

4.4 Fitting and Fastening

Care must be taken in the fit-up and fastening of pultruded FRP structures. Proper design, fabrication and assembly of pultruded FRP structures assures that forces and stresses are distributed and transmitted through the full section and not merely the outstanding projecting elements of the FRP structure. Both concentrated point loads and eccentric loading of outstanding projecting elements of a pultruded FRP structure either by design, in fabrication or in fit-up and assembly can over stress fillet areas, corners or projected element regions (see Fig. 4.2) and can cause stress cracking, delamination and ultimate failure of the structure.

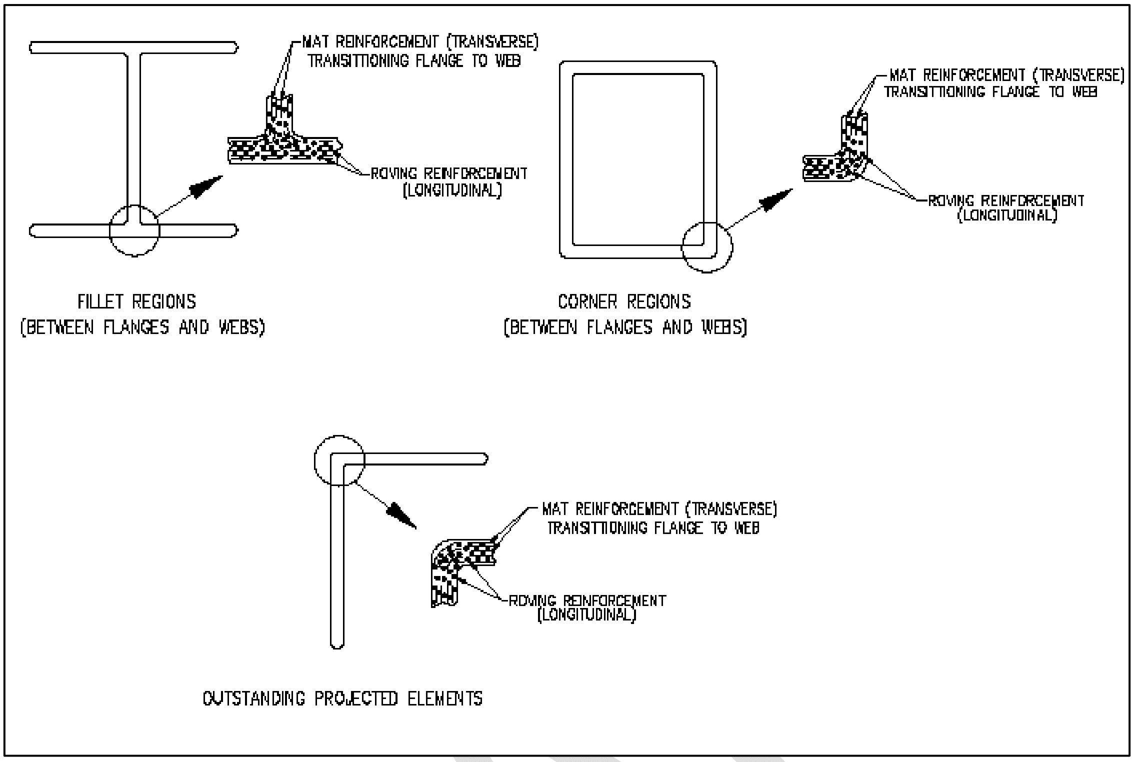

FIGURE 4.2 – REGIONS OF PULTRUDED FRP STRUCTURES SUBJECT TO STRESS CRACKING

Connections between structural members and components may be designed to transmit loads by stressing the joined components in pure compression or tension, in compressive or tensile shear, in peel or prying or in combinations thereof. Joints between the faying surfaces of fastened elements can be fastened with mechanical fasteners, by adhesive bonding or in combination using both mechanical fasteners along with adhesives. Connection design is critical to performance. Proper design must take into account all conditions and effects from each particular consideration. In some connections, keeping the joint confined by secondary clamping to allow for the proper cure of adhesive may be an important consideration. In other applications the accessibility of mechanical fasteners may be a determining factor. Selection of the fastening method(s) is generally determined by most of the following conditions:

Types of members to be connected

- Types of forces and stresses applied to the members and transferred to the connection
- Capacity requirement of the connection
- Space availability for accessing the connection
- Service environment
- Fabrication equipment and techniques available
- Need for disassembly of the connection
- Aesthetics desired
- Quality control over the preparation and application of adhesives
- Economy of the connection

In pure compression and pure tension joints such as compression load in axial loaded column splices or in bearing stiffeners on flanged girders where no eccentric loading is allowed to occur the joint is subjected to forces and stresses at right angles to the plane of the joint (See Fig. 4.3). Adhesive joints are strongest in connections in pure compression. For pure tensile joints the strength of the adhesive is usually not developed because inner-ply strength of the fiber layers of the pultruded FRP lamina and or failure of the adhesive bond line will usually control.

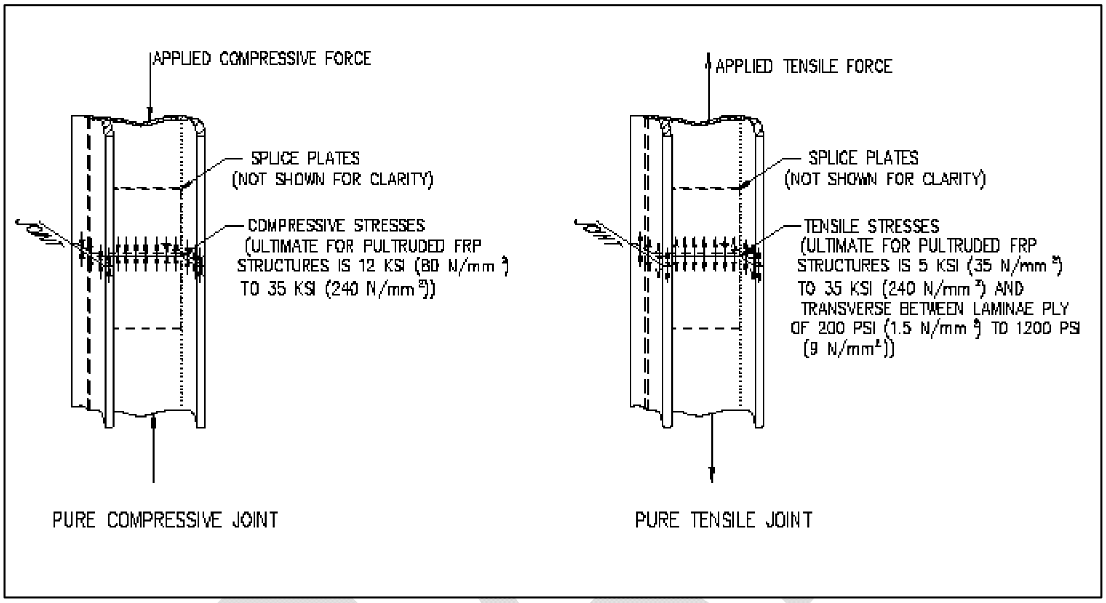

FIGURE 4.3 – FRP JOINTS SUBJECTED TO PURE COMPRESSION / TENSION

In compressive or tensile shear connections, such as lap joints of connected plates or beam cleats to other beams and or to columns, the stresses are parallel to the plane of the joint (See Fig. 4.4). For these type connections combination adhesive and mechanical joints tend to offer the optimum performance as the adhesive affords good distribution of stresses, reduces the effects of stress concentrations around fasteners at the holes and increases joint stiffness.

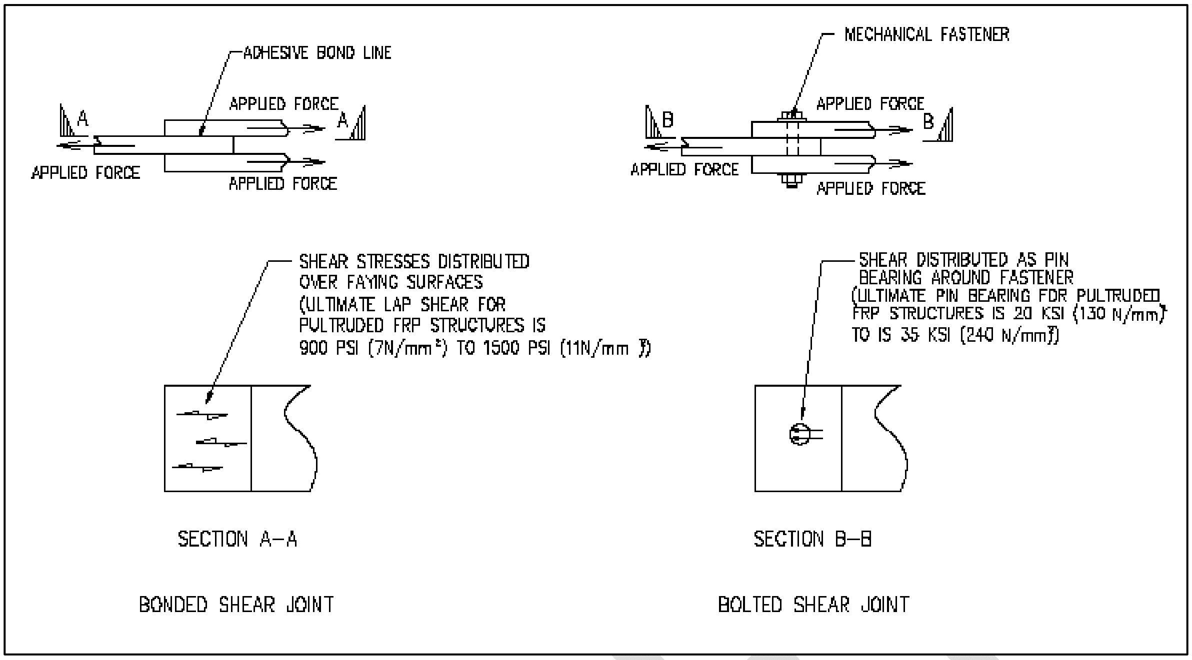

FIGURE 4.4 – FRP JOINTS SUBJECTED TO SHEAR

A connection subjected to forces and stresses at a skewed angle or offset (eccentric) forces to the plane of the joint (See Fig. 4.5) can result in prying or peeling effect within the joint. Adhesive joints are weakest in peel and cleavage in this type of stress condition and should be avoided. If peel and cleavage stresses cannot be avoided, an adhesive joint should be supplemented with mechanical fasteners. It is also critical that the inner-ply strength be understood and considered in the joint design.

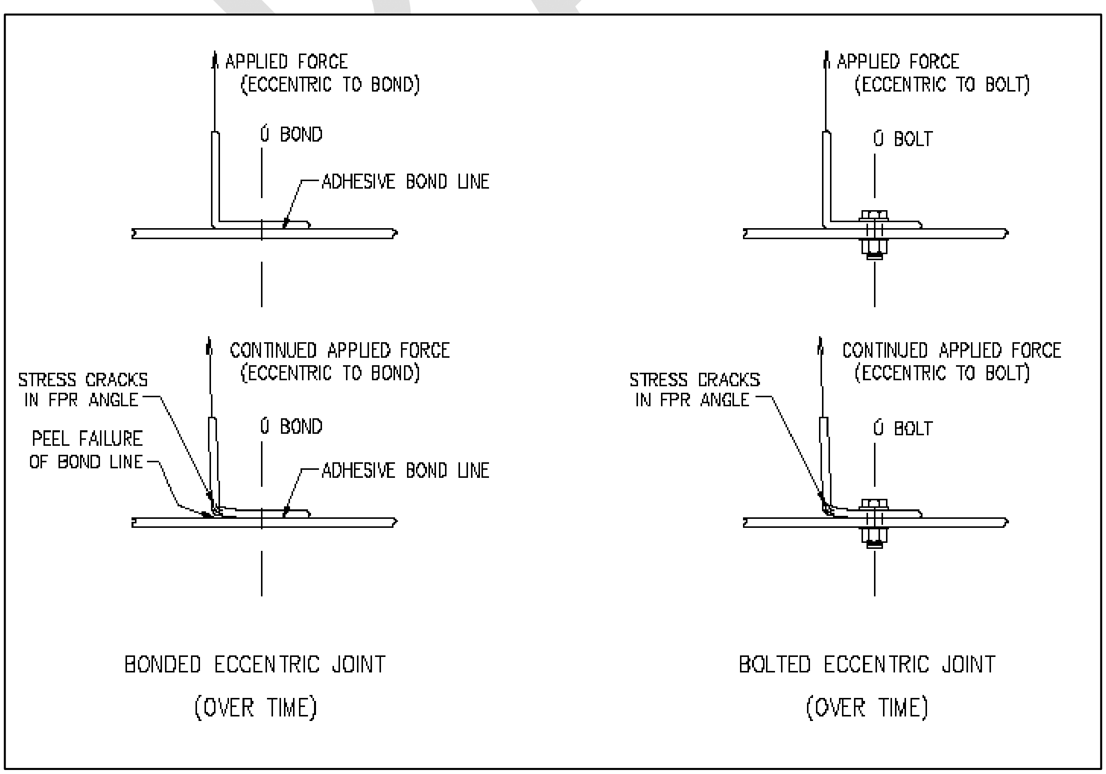

FIGURE 4.5 – FRP ECCENTRIC LOADED JOINTS SUBJECTED TO PEELING

For complex connections, critical connections wherein failure would cause collapse and imminent failure of the structure or connections where the performance of the pultruded FRP structural components and the connection components and fasteners have not been fully identified and understood, full scale performance proof testing must be incorporated. Figures 4.6a and b give caution and recommendations for loading of members and how assembly stresses should be considered in pultruded FRP structures. Figures 4.7a, b, c and d provide some common connection and joint configurations for pultruded FRP structural connections.

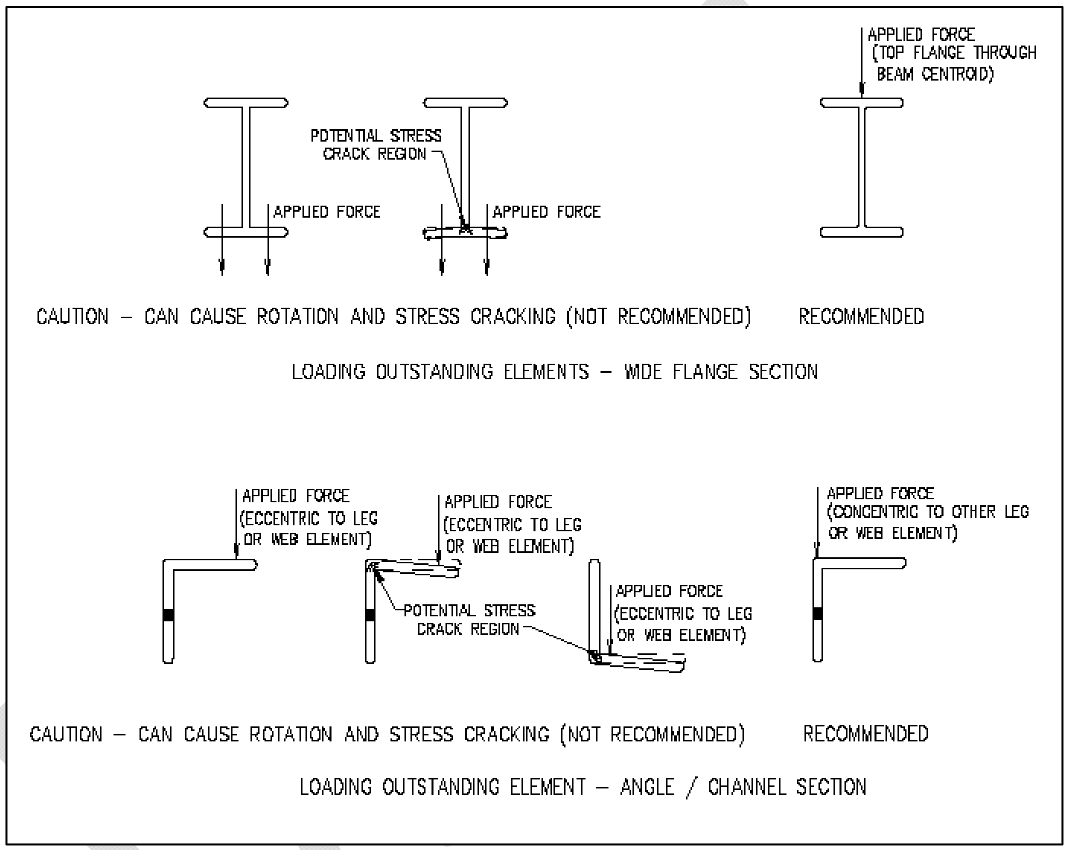

FIGURE 4.6a – RECOMMENDED LOAD AND FORCE APPLICATIONS

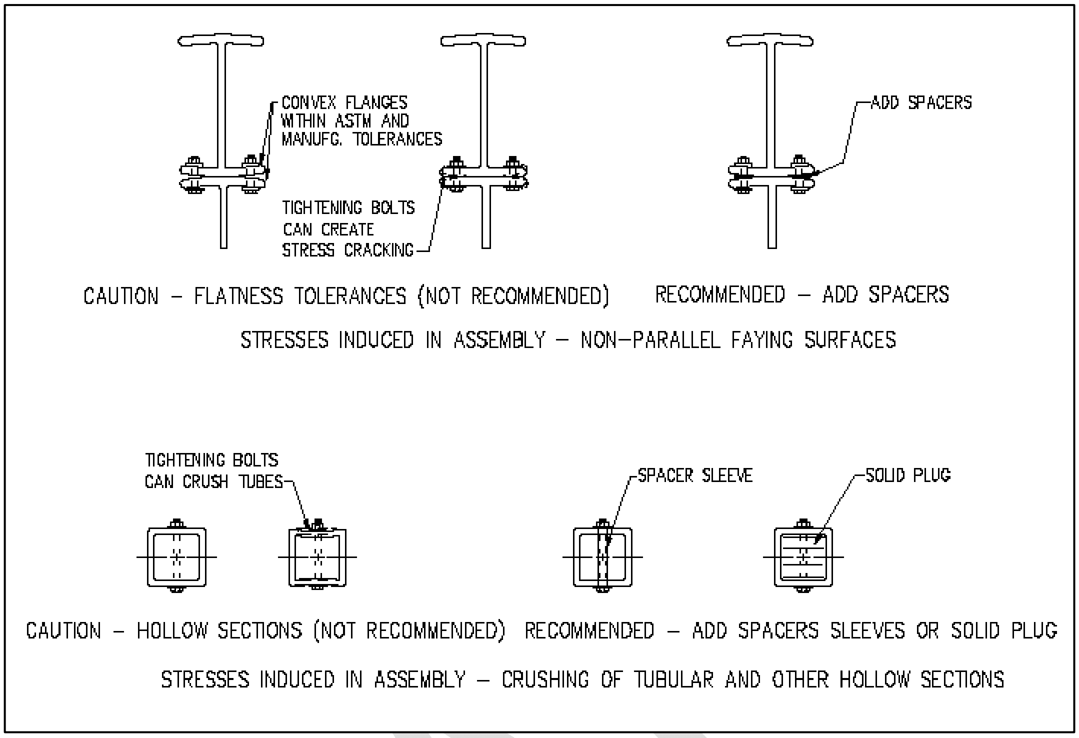

FIGURE 4.6b – RECOMMENDED LOAD AND FORCE APPLICATIONS

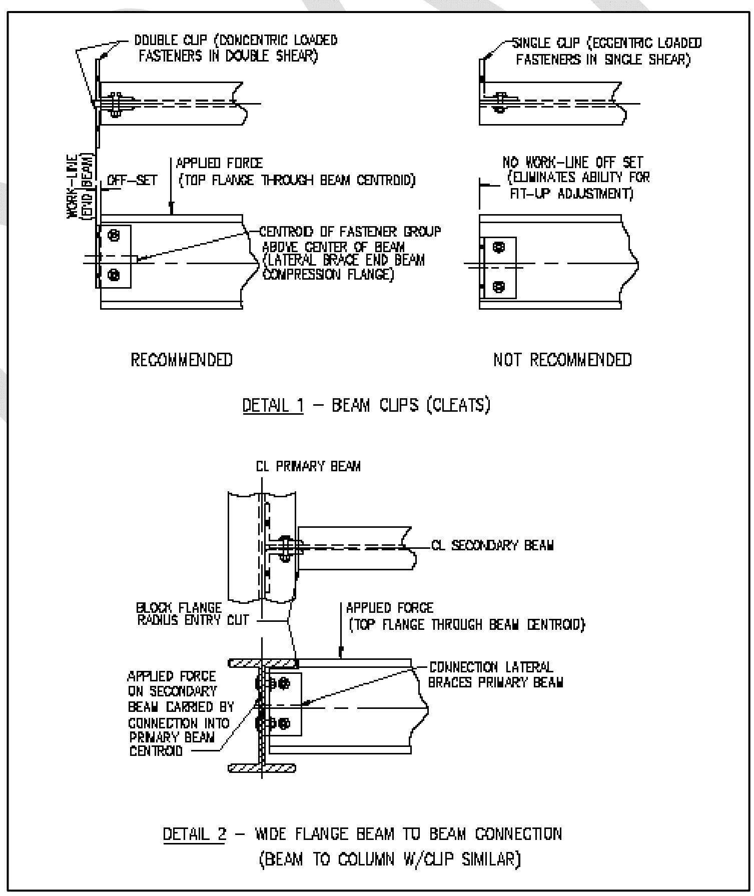

FIGURE 4.7a – PULTRUDED FRP STRUCTURAL CONNECTIONS

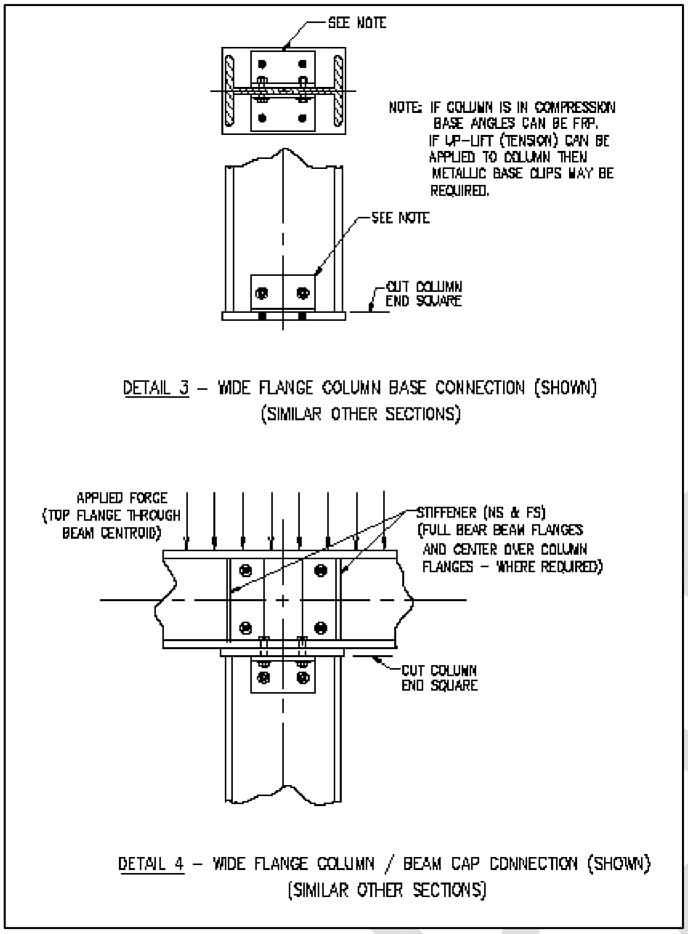

FIGURE 4.7b – PULTRUDED FRP STRUCTURAL CONNECTIONS

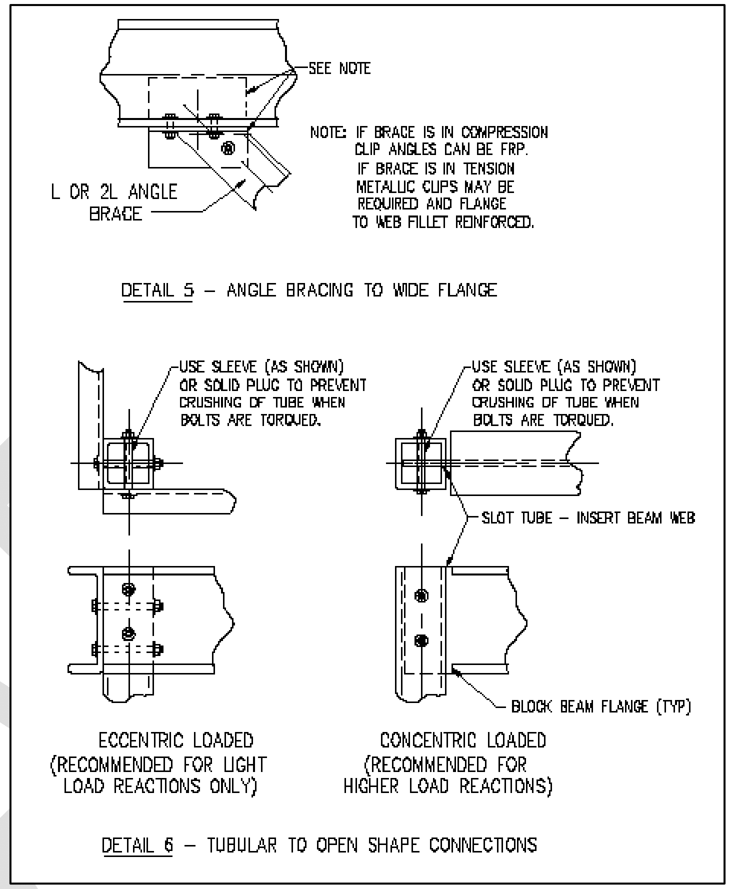

FIGURE 4.7c – PULTRUDED FRP STRUCTURAL CONNECTIONS

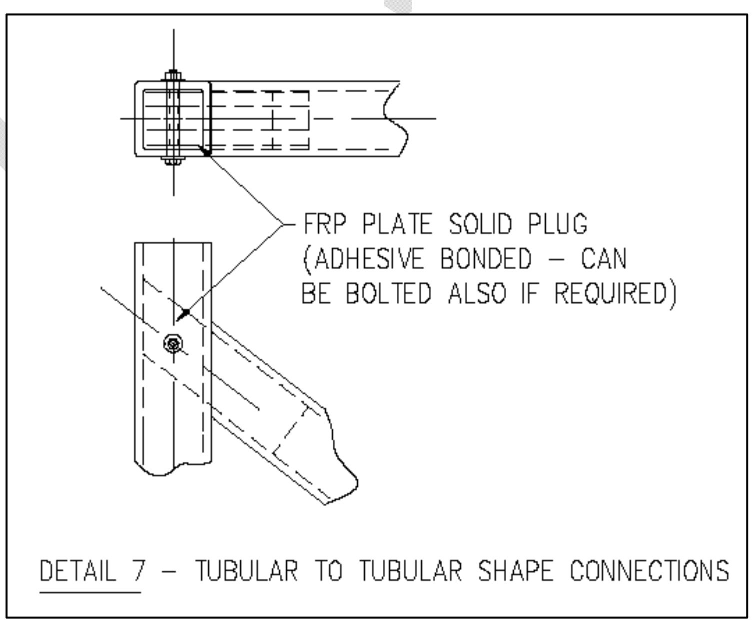

FIGURE 4.7d – PULTRUDED FRP STRUCTURAL CONNECTIONS

4.4.1 Mechanical Fastening

Mechanical fastening incorporates some type of fastener to join the assembly. This type of joint (see Fig. 4.4) is commonly controlled by the allowable pin bearing and or tear out of the mechanical fastener group. The design of the connection should give critical review of the edge distances, end distances and pitch (distance between individual fasteners). It is difficult to achieve a slip critical connection between faying surfaces of FRP without using adhesives (see Fig. 4.4) so unless the benefit of the adhesive can be demonstrated, pin bearing will control the joint design for most applications.

Some of the more common types of mechanical fasteners that can be used with pultruded FRP structures are:

- Bolt with flat washers and nut
- Toggle bolts
- Threaded rod with flat washers and nuts
- Self-tapping machine tech screws
- Thread cutting machine tech screws
- Drive pin rivets
- Blind rivets
- Solid rivets
- Nails
- Threaded inserts with bolts

In selecting the mechanical fastener system, the particular geometry of the connection and the forces and stresses within the connection must be considered.

4.4.1.1 Bolted Connections

Bolted connections (See Fig. 4.7) are made by drilling connection holes into the parts to be joined. It is recommended that the hole be + 1/16 inch (1.6 mm) larger than the bolt for bolts ½ inch (13 mm) and larger and the hole + 1/32 inch (0.8 mm) for bolts less than ½ inch (13 mm). A washer should be used under the head and under the nut for bolted connections. Counter sunk and counter bore bolts can be incorporated where required provided that the thicknesses of the components are adequate and pull through of the fastener is not an issue.

Bolts to be used in bearing-type FRP connections need only be tightened to the snug-tight condition when faying surfaces and all plies of the connection are in full bearing contact. A snug-tight condition is defined as the full effort of a worker with an ordinary spud to bring the plies into firm contact. Torque values for threaded bolts will vary depending upon the type, diameter, and application of fastener. Torque must be limited to eliminate the potential for “crushing” of the pultruded FRP laminate, especially where structural bolts of ½ inch (13mm) and greater and oversized flat washers are used. Lubricants could significantly affect torque limits. The washers should bear evenly and fully bear on the FRP surfaces. The project Engineer of Record (E-o-R) should be contacted for specific details associated to tightening of fasteners.

Some other basic considerations are appropriate as follows:

- Bolts should be cleaned of any burrs or other foreign debris.
- Oversized flat washers better distribute the stresses from bolt torquing in the fastener region.
- Verify proper alignment of the connection prior to inserting and tightening of the fasteners.
- Anti-seize lubricants will help the tendency for metallic bolts to gall.
- Tightening and torquing of bolts should be undertaken at a uniform rate and use a cross bolting pattern of tightening (tightening of one bolt will partially relieve or loosen the others as a result of elastic interaction, one with another).
- Care should be taken to verify that the faying surfaces of the connection are being brought into firm contact while the fasteners are not over tightened as to crush the FRP material.
- Lock washers, nylon locking nuts or thread locker adhesives can be incorporated to prevent loosening of bolts and to ensure that the fasteners remain secure.

4.4.1.2 Screwed Connections

Screwed connections can be made with self-tapping or thread cutting tek screws. Drilling of pilot holes may be required for screwed connections depending upon the Supplier's specifications and tolerances. Tear-out and pull-through become critical design issues for this type of connection and the capacity of the screw hold to the FRP is dependent upon type and diameter of screw, material and thread type and pitch. Screws used in combination with adhesives provide a more efficient connection as the screws will serve to hold the mating components together while the adhesive provides shear strength between the components in the joint.

4.4.1.3 Riveted Connections

Riveted connections are generally utilized in combination with adhesives in lightly loaded joints of thin materials. Back-up washers can be incorporated to distribute load stresses where required. The mating components are drilled according to the rivet supplier's specifications and tolerances.

4.4.1.4 Nailed Connections

FRP structures in some configurations may be joined to wood or other structural materials with screw or ring shank nails in combination with adhesives if the other base material provides sufficient grip to hold the nails. Temper hardened nails may be needed for the nail to penetrate the FRP unless pilot holes are drilled. Never attempt to nail FRP to FRP.

4.4.2 Adhesive Bonded Connections

Structural adhesives used in bonding of pultruded FRP structures are generally of three types: epoxy-based, polyurethanes and methacrylates. Performance of epoxy-based, polyurethane and methacrylates adhesives depends on correct joint design, careful selection of and the formulation of the adhesive system, the intended thermal and chemical service conditions, proper substrate surface preparation and application and curing of the adhesive.

An adhesive system should wet out the substrate surface, exhibit low shrinkage, provide lap shear, develop compressive/tensile capacity exceeding the substrate and be resilient to distortions that may occur in the bonded joint during its useful service life. Adhesive requirements may vary significantly within given applications and require modification of the base resin and resin additives including ("diluents," "modifiers" and "fillers"). The manufacturer and supplier of the adhesive system should be included in the proper selection and formulation of adhesive system for the application.

4.4.2.1 Preparation and Making of an Adhesive Joint

Adhesive joints of pultruded FRP structures achieve maximum performance when prepared, bonded and cured as follows:

- Remove any surface contaminant on the parts to be joined by wiping with a clean cloth dampened with a solvent as recommended by the adhesive manufacturer supplier. The FRP parts should not be immersed or soaked in the solvent.
- Remove surface veil on the pultruded FRP structures by sanding both mating surfaces with 80 grit sand paper or sanding disc. Sanding is adequate when the surfacing veil is removed down to the material substrate.
- Remove dust from the surfaces to be bonded by wiping with a clean dry rag or fine bristled brush. DO NOT wipe surface with solvent damped cloth after sanding or otherwise allow the parts to again come in contact with solvent. If surface becomes re-contaminated, repeat the above steps, including a light sanding to remove any film.
- Prepare adhesive according to adhesive manufacturer specifications and instructions.
- Apply adhesive to both parts to be joined according to the adhesive manufacture specifications and instructions, making sure that all faying surfaces have been sufficiently covered including any glass fibers that have been exposed.
- Mate parts to be joined and appropriately clamp, bolt or otherwise hold assembly secure while the adhesive cures.
- Follow adhesive manufactures instructions for cure times, but for epoxy-based and polyurethane generally it is desirable to leave the clamps in position and maintain bonding pressure for a total of 20-24 hours. The

connection should not be exposed to its full design load until the joint has cured a minimum of 48 hours pending cure temperatures. If the adhesive manufacturer's instructions should differ with this section, the instructions of the adhesive manufacturer should take precedence over these recommendations.

4.4.3 Other Connection Methods

Other specialty types of structural connections can be incorporated within pultruded FRP structures by using mechanical locking joints or by incorporating custom hardware such as splines and dowels, threaded inserts with bolts or other hardware in combination with or without adhesives. Figures 4.8a and b provide examples of other joint and connection methods. Generally, it is not recommended to attempt to drill and tap threads into pultruded FRP for structural connections. As with all fastening methods full scale performance proof testing should be incorporated to identify the performance of the connection.

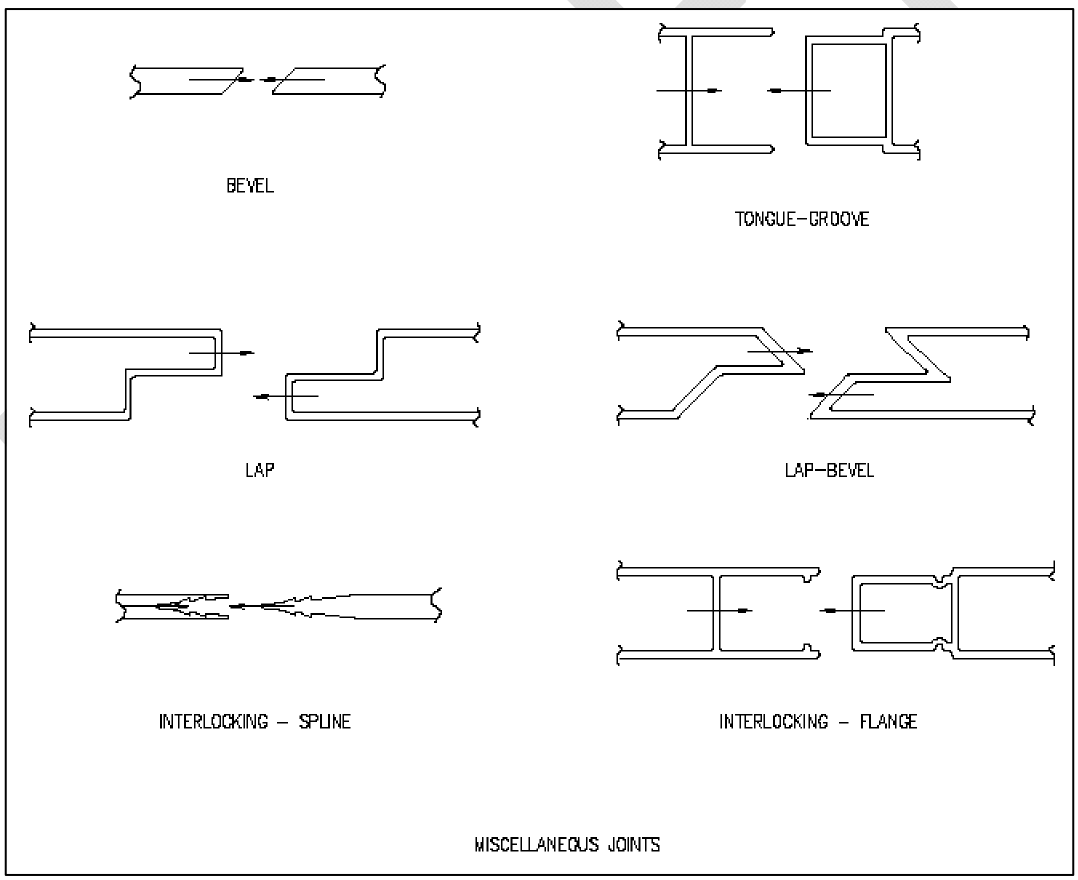

FIGURE 4.8a – OTHER JOINT AND CONNECTION METHODS

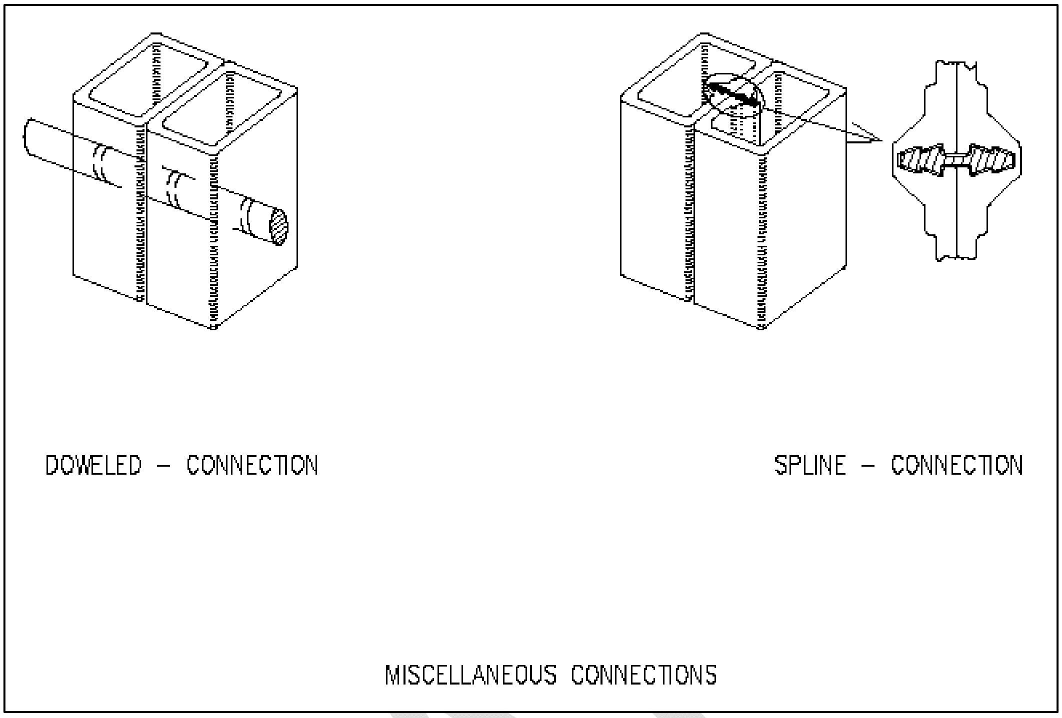

FIGURE 4.8b – OTHER JOINT AND CONNECTION METHODS

4.5 Cleaning and Sealing

4.5.1 Solvent Wipe Cleaning

Solvent wipe cleaning is achieved by wiping the surface of the pultruded FRP structure with a non-abrasive cloth dampened with a solvent or cleaning solution. It is cautioned that the solvent should be compatible with the FRP material, not be contaminated from previous use and the pultruded FRP structure should not be immersed into solvent as prolonged soaking and exposure may damage the structure. Surfaces to be adhesively bonded and that have been solvent wiped will need to be further prepared (see 4.4.2.1).

4.5.2 Steam Cleaning

Steam cleaning can be used as a routine cleaning method for pultruded FRP structures. The following procedure should be followed if the structure is to be steam cleaned:

- The steam heat temperature should not exceed 250° F and 85 psi.
- Sweep the steam back and forth over the structure.
- Do not hold the steam blast in any one spot for more than several seconds.
- Do not apply the steam directly to any adhesive bonded joints.
- Permit the structure to dry for 24 hours after steam cleaning if sealing or coating is to follow steam cleaning.

4.5.3 Pressure Washing with Water

Pressure washing with water can also be used as a cleaning method for pultruded FRP structures. The following procedure should be followed if the structure is to be pressure washed with water:

- The water to be used should be at ambient temperature.
- The water hose to be used should be equipped with a high pressure water nozzle.
- Sweep the water back and forth over the structure.
- Do not hold the water blast in any one spot for more than several seconds.
- Do not apply the water blast directly to any adhesive bonded joints.
- Permit the structure to dry for 24 hours after water cleaning if sealing and coating is to follow water cleaning.

4.5.4 Resin Sealing

Resin sealing can be used as a surface treatment and to enhance the aesthetics if desired for drilled, cut, sanded or otherwise broken surfaces of pultruded FRP structures. Resin sealing, in general, does not change the initial structural performance of the composite. The water or chemical absorption rate into the composite may be slowed when a coating or adhesive is applied to cut edges. Catalyzed resins, acrylic lacquers and oil-based, polyester, epoxy or urethane paints can all be used for sealing; however, it is recommended that the sealing resin be consistent with the resin system used in the pultruded structure. The following procedure should be followed if the structure is to be resin sealed:

- De-burr or sand to remove any shards or larger particles from areas to be sealed.
- Remove dust from the surfaces to be bonded by wiping with a clean dry rag or fine bristled brush.
- Verify that the area is free of solvents or moisture to assure proper adhesion of sealant.
- Mix, apply and cure the sealant according to the sealant manufacturer's instructions.

4.5.5 Shop Coating

Pultruded FRP structures have a synthetic surface veil which encases the glass reinforcement and adds a layer of resin at the surface. Surface coating of pultruded FRP structures further reduces the long term effects of ultra-violet radiation and can enhance the aesthetics of the system. Coating of structural members can be achieved using oil-based, polyester, epoxy, latex or urethane paints according to the manufacturer's specifications and instructions. Members specifically designated by the contact documents as "architecturally exposed FRP" require special care in manufacture, fabrication, handling and assembly to protect and preserve the surface.

Coatings should be tested for compatibility with the resin system used in the pultruded structure.

4.6 Shop Repair Procedures

4.6.1 Repairable Defects

Repairable defects are those which can be repaired without affecting the serviceability of the pultruded FRP structure. Unless otherwise specifically prohibited in the contract documents, repairable material defects include chips, die-parting lines, gouges, intermittent disfigurement, scale, sluffing, stop marks, wire brush surface and resin voids where no blisters or delamination occurs (see Appendix A and ASTM D4385 for further description and information on these defects). Unless otherwise prohibited in the contract documents, repairable fabrication defects include surface scuff marks and incorrect hole location.

4.6.1.1 Scuff Mark Repair

Scuff marks are scratches characterized as white scrape marks on the composite surface. This condition typically results from mechanical scraping of the pultruded FRP structure after manufacture in handling. If the surface has been broken, exposing the glass reinforcement, the surface should be resin sealed to maintain optimum properties. Repair is achieved by very lightly sanding the scuff marks with open grit (40-80) sandpaper and then sealing with resin (see 4.5.4)

4.6.1.2 Hole Filling

Hole filling can be utilized if an incorrectly located hole does not affect the structural integrity of the pultruded FRP structure or of the connection being prepared. Several factors affect whether a hole can be filled and the procedure required. The amount of base material removed, proximity to edge and end of the member and the proximity to other holes in the faster group critically affect the repair of an incorrectly located hole by filling. Provided that it has been verified that the structural integrity of the pultruded FRP structure is not compromised by filling the hole, the hole can be filled as follows:

- Drill the hole to the diameter of a pultruded solid dowel bar.
- Apply epoxy adhesive to both the dowel and the hole edges.
- Press the dowel into the hole.
- Allow the adhesive to cure.
- Cut the dowel as close to material being penetrated as possible.
- Grind flush and lightly sand.
- Resin seal (see Section 4.5.4).

4.7 Handling and Storage

4.7.1 Care should be exercised in the lifting and handling of pultruded FRP structures to prevent chipping, cracking, breaking, twisting or bending of the materials. If the materials are handled by fork lift, the lift should be centered and evenly distributed over the forks. If materials are handled by an over head crane, nylon lifting slings should be used.

4.7.2 Banding materials used to package or palletize pultruded FRP structures should either be nylon or plastic, or if steel banding is used packaging material such as cardboard should be incorporated to prevent steel bands from scratching or scraping the product while being handled.

4.7.3 Materials should be stored on cribbing, timbers or other dunnage capable of fully supporting the product and preventing twisting, bending or otherwise distorting of the product.

4.7.4 When pultruded FRP structures are stacked, the storing dunnage should be positioned so not to over stress or induce cracking of the product.

4.7.5 Pultruded FRP structures should not be stored where temperatures exceed 120°F (50°C). Cold temperatures are not a concern to pultruded FRP structures; however, materials should be stored in a manner to prevent water from collecting in the product and freezing.

4.7.6 Fabricated pultruded FRP structures are delivered in a sequence that will permit the most efficient and economical performance of both shop fabrication and field installation. If the Owner wishes to prescribe or control the sequence of delivery of materials, such right should be reserved and defined in the contract documents. If the Owner contracts separate delivery and installation, the Owner must coordinate the planning between the Fabricator and the Installer.

4.7.7 Bolts, hardware and other supplier furnished products are commonly shipped in separate containers according to quantity and sizes. A list and description of this product generally appears on the container.

4.7.8 The Manufacturer and Fabricator can furnish Material Safety Data Sheets (MSDS) upon request.

5.0 QUALITY CONTROL

5.1 Conformance to Design and Specifications

5.1.1 Manufacturers are to verify the mechanical, physical, and electrical properties including dimensional tolerances and visual defects of pultruded composite structural components with the manufacturers published requirements and any specific contract document requirements according to ASTM standard test protocols.

5.1.2 Manufacturers are to verify the fire rating classification performance with UL 94 or any specific contract document requirement on any area of the part. Filled core products may require other fire rating performance.

5.1.3 Manufacturers are to verify the modulus of elasticity using a three-point simply supported beam test to the published ASTM material properties for that particular composite.

5.1.4 Visual requirements are to be per ASTM D4385.

5.2 Material Inspection

5.2.1 First Article Inspections

5.2.1.1 A first article check is required for each pultrusion run documenting the conformance with Section 5.1. The Manufacturer should provide a comprehensive Quality Plan, outlining procedures relative to Section 5.2.

5.2.1.2 At the beginning of a production cycle, and prior to releasing the pultrusion machine to production status, a dimensional check of the first article is required and should be documented against the manufactures dimensional specification and/or to the requirements of ASTM D3917.

5.2.1.3 At the beginning of a production cycle, and prior to releasing the pultrusion machine to production status, a screen test for UL 94 (V0) verification is required to be performed and documented.

5.2.1.4 At the beginning of a production cycle, and prior to releasing the pultrusion machine to production status, a screen test for evaluating the Modulus of Elasticity (MOE) is required to be performed and documented. The test must demonstrate that the minimum specified MOE is being achieved.

5.2.2 Rejectable Defects

5.2.2.1 Rejectable visual defects for structural issues include blisters, cracks, delaminations and insufficient cure and must be evaluated against the Manufacturer's minimal requirements and or ASTM D4385.

5.2.2.2 Rejectable defects for corrosion performance include poor veil coverage and insufficient cure and must be evaluated against the Manufacturer's minimal requirements and/or ASTM D4385.

5.2.2.3 Rejectable defects for visual issues are to be defined by the contract according to Section 2.5.

5.2.3 Maintenance of Records

5.2.3.1 First article check records must be maintained for a minimum of 2 years.

5.2.3.2 Records of nonconforming product accepted by the Owner must be maintained for a minimum of 2 years.

5.3 Fabrication Inspection

5.3.2 Fabricators are to ensure that the product to be fabricated conforms to the visual and dimensional requirements as depicted in the contract documents and approved FRP drawings (see 3.0).

5.3.3 Fabricators are to inspect the actual fabrication performed against the approved FRP drawings (see 3.0). The inspections should be documented as defined in the Manufacturer's Quality Assurance plan.

5.3.4 Fabrication Inspection Records must be maintained for 1 year.

5.4 Internal Auditing

5.4.1 The Manufacturer should retain evidence of annual audits to their current Quality System plan either by independent auditing or self auditing to ensure that the Manufacturer's process is conforming and effective.

5.4.2 Independent Audit

5.4.2.1 It is recommended that the Manufacturer have an ISO 9001: (current year) or other independent certification to ensure that the Manufacturer's process has been independently audited for conformance.

5.5 Applicable Testing Procedures for Support of Structural Design

5.5.1 ASTM D638 - Standard Test Method for Tensile Properties of Plastics

5.5.2 ASTM D695 - Standard Test Method for Compressive Properties of Rigid Plastics

5.5.3 ASTM D790 - Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

5.5.4 ASTM D953 - Standard Test Method for Bearing Strength of Plastics

5.5.5 ASTM D2344 - Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates

5.5.6 ASTM D5379 - Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method

5.5.7 ASTM D6641 - Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using Combined Loading Compression (CLC) Test Fixture

5.5.8 ASTM D7332/Proc. B - Standard Test Method for Measuring the Fastener Pull-through Resistance of a Fiber-Reinforced Polymer Matrix Composite

6.0 INSTALLATION

6.1 Method of Assembly

6.1.1 FRP structures should be assembled in a manner that conforms to the requirements of the Contract Documents. Installation methods and sequences employed should be practical, efficient and economical.

6.1.2 If at all, there is a change in preference of methods and sequences of installation by any party involved, for any valid reason, the Contract Documents should be modified to reflect this change.

6.1.3 Any installation changes that might necessitate redesigns should be brought to the Fabricator's attention prior to the preparation of Shop and Installation drawings thus allowing for Owner's approval. Last minute changes should be discouraged.

6.2 Foundations, Points of Attachment, Field Control and Bench Lines

6.2.1 It is the Owner's responsibility to provide easy approach to all foundations and points of attachments for structures. The Owner is also responsible for the strength and appropriateness of all foundations and points of attachments for structures.

6.2.2 The Owner is to provide adequate access to the job site and a suitable operating space for the Installer to install the structures.

6.2.3 The accurate location of site Bench Lines and the conveyance of such information in the form of plans to the Installer is the responsibility of the Owner.

6.3 Anchorage and Anchor Bolts

6.3.1 Anchor Bolts should be installed per the Installation Drawings that have been approved by the Owner and that show anchor positions and embedment.

6.3.2 Recommended tolerances (unless otherwise provided by the Owner) for anchor bolt locations are to be as follows:

- 1/8 inch maximum variation in dimension taken center to center of any two bolts set inside an anchor bolt group.
- ¼ inch maximum variation in dimension taken center to center of adjacent anchor bolt groups.

- +/- ½ inch maximum variation in elevation of the top of anchor bolts.
- ¼ inch maximum accumulation per 100 feet along the center line of a series of anchor bolt groups but not exceeding a total of 1 inch.
- ¼ inch maximum variation in dimension taken from the center of an anchor bolt group to the column line through that group.

6.3.3 Anchor bolts are to be installed perpendicular to the mounting surface unless specified otherwise. A +/- 2 degree variance from the vertical is allowable.

6.4 Field Connection Material and Bolting Schedule

6.4.1 The Fabricator should provide the Installer, as a part of their shop drawings, field connection details that will meet the requirements of the contract documents. These details should clearly designate the extent of shop fabrication of the connection details and any field drilling that may be required.

6.4.2 The Fabricator should provide all bolts, nuts, washers, rivets, adhesives and other connection materials required to complete all FRP to FRP connections. Where adhesives and other specialty fasteners are to be used, the Fabricator should provide the Installer with installation instructions for these products.

6.4.3 Unless specifically agreed to by the Fabricator, all anchor rods, foundation bolts and other points of attachment to adjacent structure are to be supplied by the Owner. Materials used for the connection of the FRP frame to non-concrete items should be specified in details provided by the Fabricator to be consistent with the contract documents. Supply of these materials is subject to agreement between the Fabricator and the Owner or Installer.

6.5 Field Connection Procedures

6.5.1 The Fabricator should provide the Installer, as a part of the Shop Drawings, field connection details that include the sizes of the connection components including the diameter and lengths of bolts and bolt material and type, the size and lengths of any ship loose connection angles or splice plates, and information required to properly identify all components. If bolted fasteners are to be installed other than to the snug tight condition the Fabricator should also include the recommended bolt torque by bolt diameter. The details must include any special instructions for successful completion of the connection in the field.

6.5.2 For bolted connections, the Fabricator is to, where practical, shop-install the connection angles and splice-plates to the ends of beam, bracing and column shipping units. Bolts for these Fabricator-installed connection components are to be tightened to the snug-tight condition or to the condition(s) as specified in the shop drawings.

6.5.3 To install the fabricated FRP units with bolts, bring the components into alignment such that the mating surfaces are flush and the holes are in alignment with each other. Under no circumstances are the bolts to be used to pull the assemblies into alignment.

The bolts are to be installed with flat washers and/or lock washers as specified in the shop drawings. Torque all nuts to a finger tight condition until satisfactory alignment of the assembly is achieved. Once alignment of the assembly is achieved, the field installed bolts can be tightened to the snug-tight condition or to the condition(s) as specified in the shop drawings and/or installation guidelines provided by the Fabricator.

6.5.4 For bolted connections where FRP bolts are to be used, the Fabricator is to provide the Installer with complete instructions on their installation. These instructions are to include maximum allowable torque, thread locking procedures and procedures for sealing exposed threads where applicable.

6.5.5 For connections that are field bonded, the Fabricator is to provide a complete procedure to the Installer for completion of the bonded connection. This procedure must include the following information in order to be considered complete:

- Surface preparation requirements for the bonded surfaces of the connection, including sanding, cleaning or solvent preparation.
- If the adhesive is not supplied by the Fabricator, identification of the adhesive to be used, including manufacturer and product name.
- Mixing and application instructions for the adhesives, including mix ratio, allowable temperature range and adhesive working time.
- Application procedure including quantities, clamping procedure/time and clean up.
- Minimum allowable adhesive curing time to develop full connection strength.

6.6 Temporary Support of Frames

6.6.1 The Installer should determine, furnish and install all temporary support and stabilization devices required to maintain stability of the FRP structure during the erection process. These devices can consist of, but are not limited to, guys, beams, false work and temporary bolting. These temporary support and stabilization devices are to be sized by the Installer to be adequate for resisting all loads that are likely to be encountered during the erection process, including those expected from erection activities, wind loads and other typical environmental loads.

6.6.2 Unless directed by the Contract Documents, the temporary support and stabilization devices do not need to be sized to resist loads generated by the work of other trades or from unpredictable environmental loads such as hurricanes, tornadoes, earthquakes, explosions or collisions.

6.6.3 The Installer should be responsible for following all applicable safety regulations and codes during the erection of the FRP structure.

6.7 Position and Alignment

6.7.1 Erection tolerances are to be defined relative to member work points and lines.

6.7.2 Axially Loaded Columns

6.7.2.1 For an individual, unspliced column, the angular variation of the working line of the column from a true plumb line should not exceed a slope of 1/500. In addition, the horizontal displacement of the work point at the top of the column should be equal to or less than +/- 1 inch from the established column line regardless of column length.

6.7.2.2 At the connection of the column base to the foundation the horizontal location of the column work point relative to the established column lines should not vary by an amount greater than +/- 1/4 inch.

6.7.2.3 For spliced columns in multi-tiered structures, the angular variation of the working line of any individual column shipping piece from a true plumb line should not exceed a slope of 1/500. For individual column shipping units within the spliced column, the displacement of member working points should be equal to or less than ± 1 inch from the established column line regardless of structure height.

6.7.3 Members Other Than Columns

6.7.3.1 Any variation in alignment of secondary members is acceptable if caused by the variation in alignments of columns or primary members that are within allowable fabrication limits.

6.7.3.2 For members connecting to columns, the maximum variation in vertical distance specified from the member working point to the upper splice line of the column should not be more than +/- 3/16 inch.

6.7.3.1 For members other than those connecting to columns, the variation in elevation is acceptable if caused by the variation in elevations of the members being tied into, given that they are within allowable fabrication limits.

6.7.3.2 An individual unspliced member is to be considered to be installed level and plumb and in proper alignment if the angular variation of the working line of the member from the plan alignment does not exceed a slope of 1/500.

6.8 Correction of Errors

6.8.1 Standard installation operations incorporate the modification of minor misfits by reasonable amounts of cutting, drilling or reaming and the drawing of elements into alignment with drift pins. Errors that cannot be rectified by the preceding methods or that require major changes in member or connection configuration are to be reported to the Owner and Fabricator by the Installer, to enable the responsible party to correct the error.

6.9 Acceptance of Position and Alignment

6.9.1 The Owner is responsible for determining that the location of the FRP Structure is acceptable for plumbness, level and alignment within tolerances upon completion of installation of the FRP Structure and prior to the start of work by other trades that may be supported, attached or applied to the FRP Structure.

APPENDIX A - GLOSSARY

A

Abrasion - The wearing away of materials by friction. Particles become detached by a combined cutting shearing and tearing action.

Abrasive Resistance - The ability of a surface to resist wear due to rubbing and friction.

Absorbed Moisture - Moisture that has entered a solid by absorption and has physical properties not substantially different from ordinary water at the same temperature and pressure.

Absorption - The process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body; also the increase in weight of a porous solid body resulting from the penetration of a liquid into its permeable pores.

Accelerator - A material that acts synergistically with the promoter to speed up the chemical reaction between the catalyst and the resin.

Acoustic Emission - A measure of integrity of a material, as determined by sound emission when a material is stressed. Ideally, emissions can be correlated with defects and/or incipient failure.

Additive - A substance added to polymer resin, to improve properties and or aid in processing. Examples are plasticizers, initiators, light stabilizers and flame retardants.

Adhesives - The group of materials used to join or bond similar or dissimilar materials; for example, in FRP bonded connections, the epoxy-based, polyurethane and methacrylates capable of holding FRP composites together by surface attachment.

Adhesion - The state in which two surfaces are held together by interfacial forces.

Ambient Temperature - The environmental temperature surrounding the object under construction.

Anisotropic - Exhibiting different properties when tested along axes in different directions.

Anisotropic Laminate - One in which the properties are different in different directions.

Antioxidant - A substance that, when added in small quantities to the resin prevents its oxidative degradation and contributes to the maintenance of its properties.

B

Barcol Hardness - A hardness value, obtained by measuring the resistance to penetration of a sharp steel point under a spring load. The instrument, called the Barcol impressor, gives a direct reading on a 0 to 100 scale. The hardness value is often used as a measure of the degree of cure of a plastic.

Barcol Hardness Test - Test to determine degree of cure by measuring resin hardness (ASTM D 2583).

Batch - In general, a quantity of material formed during the same process or in one continuous process and having identical characteristics throughout. Commonly referred to as "lot."

Binder - The resin or cementing constituent (of a plastic compound) that holds the other components together. Also the agent applied to fiber mat or preforms to bond the fibers before laminating or molding.

Blister - A raised area on the surface of a laminate caused by the presence of gases under pressure within the substrate.

Bond - The adhesion and grip of a material to other surfaces against which it is placed.

Bond Area - The nominal area of interface between two elements across which adhesion develops or may develop.

Bond Strength - The amount of adhesion between bonded surfaces. The stress required to separate a layer of material from the base to which it is bonded, as measured by load/bond area.

Bridging - Condition in which fibers do not move into or conform to radii and corner during molding, resulting in voids and dimensional control problems.

C

Carbon Fiber - Fiber produced by the prolysis of organic precursor fibers, such as rayon, polyacrylonitrile (PAN) and pitch, in an inert environment.

Catalyst - A substance that initiates a chemical reaction and enables it to proceed under milder conditions than otherwise required and which does not, itself, alter or enter into the reaction. See initiator, the more common term for addition polymerization.

CFRP - Carbon fiber reinforced polymer (includes graphite fiber reinforced polymer).

Coating - Material applied to a surface by brushing, dipping, mopping, spraying, toweling, etc., to preserve, protect, decorate, seal or smooth the substrate; also refers to foreign or deleterious substances found adhering to aggregate particles.

Coefficient of Thermal Expansion - Changes in linear dimension per unit length, or change in volume per unit volume per degree of temperature change.

Compatibility - The ability of two or more substances combined with one another to form a homogeneous composition of useful plastic properties; for example, the suitability of a sizing or finish for use with certain general resin types.

Composite - A combination of one or more materials differing in form or composition on a macroscale. The constituents retain their identities; i.e., they do not dissolve or merge completely into one another, although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another (see FRP Composite).

Continuous Roving - Parallel filaments coated with sizing, drawn together into single or multiple strands and wound into a cylindrical package.

Corrosion Resistance - The ability of a material to withstand contact with ambient natural factors or those of a particular artificially created atmosphere, without degradation or change in properties. For metals, this could be pitting or rusting; for organic materials, it could be crazing.

Coupling Agent - Any chemical substance designed to react with both the reinforcement and matrix phases of a composite material to form or promote a stronger bond at the interface.

Crack - A complete or incomplete separation of two or more parts, produced by breaking or fracturing.

Crazing – Cracking of the resin due to internal stress. Region of ultra fine cracks, which may extend in a network on or under the surface of a resin or polymer that may appear as a white band.

Cure - To irreversibly change the properties of a thermosetting resin by chemical reaction, that is, condensation, ring closure, or addition. Cure may be accomplished by addition of curing (cross-linking) agents, with or without heat and pressure.

Cure Cycle - The time/temperature/pressure cycle used to cure a thermosetting resin system or prepreg.

D

Delamination - Separation of the layers of material in a laminate, either local or covering a wide area. Can occur in the cure or subsequent life.

Discoloration - Departure of color from that which is normal or desired.

Ductility - That property of a material that may cause it to undergo large permanent deformation without rupture. The ability of a material to deform plastically before fracturing.

Durability - The ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.

E

E-Glass - A family of glasses with a calcium alumina borosilicate composition and a maximum alkali content of 2.0%. A general-purpose fiber that is most often used in reinforced polymers, and is suitable for electrical laminates because of its high resistivity for conducting electricity.

Epoxy - A polymerizable thermoset polymer containing one or more epoxide groups and curable by reaction with amines, alcohols, phenols carboxylic acids, acid anhydrides and mercaptans. An important matrix resin in composites as a structural adhesive.

F

Fabric - Arrangement of fibers held together in two dimensions. A fabric may be woven, nonwoven or stitched.

Fiber - A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament.

Fiber Architecture – The design of a FRP composite laminate where the fibers are arranged in a particular orientation (0, 90, +45, -45, etc.) to achieve a desired strength or stiffness of the product.

Fiber Content - The amount of fiber present in a composite. This is usually expressed as a percentage volume fraction or weight fraction of the composite.

Fiber Direction - The orientation or alignment of the longitudinal axis of the fiber with respect to a stated reference axis.

Fiber Volume Fraction – The ratio of the volume of fibers to the volume of the composite.

Fiber Weight Fraction - The ratio of the weight of fibers to the weight of the composite.

Fiber Reinforced Polymer (FRP) - A general term for a composite material comprising a polymer matrix reinforced with fibers in the form of fabric, mat, strands or any other fiber form

Fiberglass Reinforcement - Major material used to reinforce polymer. Available as mat, roving, fabric, etc., it is incorporated into both thermosets and thermoplastics.

Filament - Smallest unit of a fibrous material. A fiber made by spinning or drawing into one long continuous entity.

Filler - A relatively inert substance added to a material to alter its physical, mechanical, thermal, electrical and other properties or to alter cost or density. Sometimes the term is used specifically to mean particulate additives.

Fire Resistance - The property of a material or assembly to withstand fire or give protection from it; as applied to elements of buildings, it is characterized by the ability to confine a fire or to continue to perform a given structural function, or both.

G

GFRP - Glass fiber reinforced polymer.

Glass Fiber - Fiber drawn from an inorganic product of fusion that has cooled without crystallizing. Types of glass fiber include general purpose (E-glass), high strength (S-glass), and alkali resistant (AR-glass).

Glass-Transition Temperature - The midpoint of the temperature range over which an amorphous material changes from (or to) a brittle, vitreous state to (or from) a plastic state.

H

Hardener - Substance added to thermoset resin to cause curing reaction. Usually applies to epoxy resins.

Hybrid - A composite laminate consisting of laminae of two or more composite material systems. A combination of two or more different fibers, such as carbon and glass or carbon and aramid, into a structure.

I

Impregnate - In reinforced polymers, to saturate the reinforcement with a resin.

Inhibitor - A substance that retards a chemical reaction. Also used in certain types of monomers and resins to prolong storage life.

Initiator - Peroxides used as sources of free radicals. They are used in free-radical polymerizations, for curing thermosetting resins, as cross-linking agents for elastomers and poly-ethylene, and for polymer modification.

Isophthalic Polyester **-** High quality polyester resin (good thermal, mechanical, chemical resistance).

L

Laminate - To unite layers with a bonding material, usually with pressure and heat (normally used with reference to flat sheets, but also rods and tubes). Also a material consisting of layers bonded together.

M

Mat - A fibrous material for reinforced polymer consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric) or swirled filaments loosely held together with a binder.

Matrix - The essentially homogeneous resin or polymer material compound in which the fiber system of a composite is embedded.

N

Nondestructive Inspection (NDI) - A process or procedure, such as ultrasonic or radiographic inspection, for determining the quality or characteristics of a material, part, or assembly, without permanently altering the subject or its properties.

Nondestructive Testing (NDT) - Broadly considered synonymous with nondestructive inspection (NDI).

P

Phenolic (Phenolic Resin) - A thermosetting resin produced by the condensation of an aromatic alcohol with an aldehyde, particularly of phenol with formaldehyde.

Pin Holes - Small cavities that penetrate the surface of a cured part.

Pit - A small, regular or irregular crater in the surface of a plastic, usually of a width approximately the same order of magnitude as its depth.

Ply - In general, fabrics or felts consisting of one or more layers (laminates, and so forth). The layers that make up a stack.

Polyester - One of a large group of synthetic resins, mainly produced by reaction of dibasic acids with dihydroxy alcohols; commonly prepared for application by mixing with a vinyl-group monomer and free-radical catalysts at ambient temperatures and used as binders for resin mortars and concretes, fiber laminates (mainly glass), adhesives, etc. (See also concrete, polymer.)

Polymer - A compound formed by the reaction of simple molecules having functional groups, which permit their combination to proceed to high molecular weights under suitable conditions.

Polyurethane - A thermosetting resin prepared by the reaction of disocyanates with polyols, polyamides, alkyd polymers and polyether polymers.

Pot Life - The length of time that a catalyzed polymeric resin system retains a viscosity low enough to be used in processing.

Promoter - A chemical reduces the activation energy required for a given initiator.

Pultrusion - A continuous process for manufacturing composites that have a constant cross-sectional shape. The process consists of pulling a fiber-reinforcing material through a resin impregnation bath and through a shaping die, where the resin is subsequently cured.

Q

Quality Assurance - A system that ensures that the intended levels of quality on a project are obtained.

Quality Control - Actions taken by a producer or contractor to provide control over what is being done and what is being provided so that the applicable standards of good practice for the work are followed.

R

Reinforcement - Strong materials bonded to or into a matrix to improve mechanical properties. Materials, ranging from short fibers through complex textile forms, that are combined with a resin to provide the composite with enhanced mechanical properties.

Resin - A natural or synthetic viscous liquid, solid or semisolid, organic material of indefinite and often high molecular weight having a tendency to flow under stress, usually has a softening or melting range and usually fractures conchoidally. Polymeric material that is rigid or semi-rigid at room temperature, usually with a melting point or glass transition temperature above room temperature.

Resin Content - The amount of resin in a laminate expressed as either a percentage of total weight or total volume.

Roving - A number of yarns, strands, tows or ends collected into a parallel bundle with little or no twist.

S

S-Glass - A magnesium alumina silicate composition that is especially designed to provide very high tensile strength glass filaments.

Shelf Life - The length of time a material, substance, product or reagent can be stored under specified environmental conditions and continue to meet all applicable specification requirements and/or remain suitable for its intended function.

Sizing - Surface treatment or coating applied to filaments to improve the filament-to-resin bond and to impart processing and durability attributes.

Solvent - A liquid used to dissolve and clean materials.

Storage Life - The period of time during which a liquid resin, packaged adhesive or prepreg can be stored under specified temperature conditions and remain suitable for use. Also called shelf life.

Strand - Bundle of filaments bonded with sizing.

T

Thermal Conductivity - The property (of a homogeneous body) measured by the ratio of the steady-state heat flux (time-rate of heat flow per unit area) to the temperature.

Thermoplastic - Resin that is not cross linked. Thermoplastic resin generally can be remelted and recycled.

Thermoset - Resin that is formed by cross linking polymer chains. A thermoset cannot be melted and recycled because the polymer chains form a three dimensional network.

Tow - An untwisted bundle of continuous filaments. Commonly used in referring to man-made fibers, particularly carbon and graphite, but also glass and aramid. A tow designated as 140K has 140,000 filaments.

U

Unidirectional Laminate - A reinforced polymer laminate in which substantially all of the fibers are oriented in the same direction.

Unsaturated Polyester - Product of a condensation reaction between dysfunctional acids and alcohols, one of which, generally the acid, contributes olefinic unsaturation.

V

Veil - An ultrathin mat similar to a surface mat often composed of organic fibers as well as glass fibers.

Vinyl Esters - A class of thermosetting resins containing ester of acrylic and/or methacrylic acids, many of which have been made from epoxy resin.

W

Wet-Out - The condition of an impregnated roving or yarn in which substantially all voids between the sized strands and filaments are filled with resin.

Woven Fabric - A material (usually a planar structure) constructed by interlacing yarns, fibers, or filaments, to form such fabric patterns as plain, harness satin or leno weaves.